ANALYSIS OF MAXILLARY POSTERIOR TEETH WITH CONE BEAM COMPUTED TOMOGRAPHY

by

Kelvin Z. Chou, D.D.S.
Lieutenant, Dental Corps
United States Navy

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CERTIFICATE OF APPROVAL

MASTER'S THESIS

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Kelvin Z. Chou

has been approved by the Examining Committee for the thesis requirement for the Master of Science degree in Oral Biology at the June 2017 graduation.

Research Committee:

Terry D. Webb, D.D.S., M.S.
Captain, Dental Corps, US Navy
Chairman, Endodontics Department

Calvin B. Suffridge, D.D.S., M.S.
Commander, Dental Corps, US Navy
Program Director, Endodontics Department

Glen M. Imamura, D.D.S., M.S.
Captain (Ret.), Dental Corps, US Navy
Research Department

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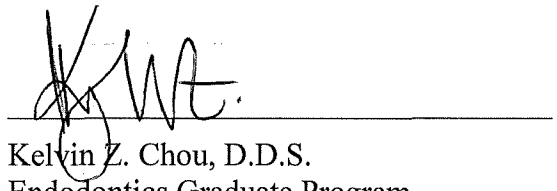

Kelvin Z. Chou, D.D.S.
Endodontics Graduate Program
Naval Postgraduate Dental School
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KELVIN Z. CHOU

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ABSTRACT

ANALYSIS OF MAXILLARY POSTERIOR TEETH WITH CONE BEAM COMPUTED TOMOGRAPHY

KELVIN Z. CHOU
D.D.S., ENDODONTICS, 2017

Directed by: CDR Calvin Suffridge, D.D.S., M.S., Endodontics Department Program Director, Naval Postgraduate Dental School

Introduction: Endodontic surgery of maxillary posterior teeth can be challenging due to the location of the maxillary sinus relative to the tooth root as well as the thickness of buccal cortical bone. Three dimensional imaging, utilizing cone-beam computed tomography (CBCT), has improved the clinician's ability to understand the relationship of these anatomical structures. There is limited research measuring these dimensions and no published literature solely utilizing limited field of view (FOV) CBCT. **Objectives**: Measure the distance from the root apex to the floor of the maxillary sinus (FMS) and buccal bone thickness (BT) at the site of root resection in maxillary posterior teeth. A secondary objective correlated buccal BT with age. **Materials and Methods**: 128 anonymized limited FOV CBCTs met the inclusion criteria. Measurements from the root to the FMS were recorded in the corrected sagittal plane. The buccal BT, at the level of root resection (3.0 or 3.6 mm), was recorded in the axial plane and compared to the patient's age using logistic regression. **Results**: 420 maxillary posterior teeth were evaluated. The longest and shortest mean distance of root apices to the FMS were the buccal root of the first premolar (6.23 mm) and mesiobuccal (MB) root of the second molar (0.53 mm) respectively. The thickest mean buccal BT was covering the MB root of the second molar (2.31 mm) and the thinnest was covering the buccal root of the first premolar (0.59 mm). No correlation between buccal BT and

age was noted. **Conclusions**: The first premolar presented with the longest distance while the MB root of the second molar was the shortest distance to the FMS. The buccal bone was thickest over the MB root of the second molar and thinnest over the first premolar. There was no correlation between buccal BT and age.

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LIST OF ABBREVIATIONS

2-D	2 dimensional
3-D	3 dimensional
BT	bone thickness
CBCT	cone beam computed tomography
CI	confidence interval
cm	centimeters
CS	CareStream©
DB	distal buccal
FMS	floor of maxillary sinus
FOV	field of view
IRB	Institutional Review Board
MB	mesial buccal
NSRCT	non-surgical root canal treatment
mm	millimeters
SPSS	Statistical Package for the Social Sciences (IBM, inc.)

Chapter I: Introduction

In the classic study by Kakahashi et al. (1), bacteria were identified as the primary cause of pulpal infection. When left untreated, the resulting tooth pain, swelling, and discomfort are indicative of non-surgical root canal treatment (NSRCT). Conventional NSRCT combines mechanical and chemical techniques to clean, debride and disinfect the pulp canal space prior to obturation. In cases where conventional NSRCT fails due to recurrent bacterial contamination or persistent infection, alternative treatments other than tooth extraction are available. Based on case selection, the patient may be a candidate for non-surgical retreatment or endodontic microsurgery.

Endodontic microsurgery has led to favorable outcomes when initial NSRCT has failed to produce the desired results (2). For cases that involve root end resection, a comprehensive understanding of the relationships between the tooth root and surrounding anatomical structures is required. In the posterior maxillary region, comprehending the relationships between posterior teeth root apices and the floor of the maxillary sinus (FMS) will assist the clinician in minimizing surgical complications such as sinusitis, sinus perforation, oroantral communication, and root displacement into the sinus. Similarly, knowledge of the buccal bone thickness (BT) in this region also provides vital information in planning surgical access.

During the preoperative surgical evaluation, radiographs are used to analyze topographical relationships between the root apices to the FMS, the amount of bone between the apices, and buccal cortical BT at the ostecomy site. Maxillary posterior tooth roots, viewed with a panoramic image, appear to project into the sinus 39% of the time (3) but actually perforate the sinus only 9.6% of the time when periapical surgery (4) is performed. These studies demonstrated that relationships between the roots of maxillary posterior teeth and the sinus

cannot be accurately predicted using conventional radiography. The use of 3-dimensional cone beam computed tomography (CBCT) overcomes some limitations of 2 dimensional (2-D) images (5).

Kwak et al (6) used CBCT imaging and determined the sinus lies in between the roots 80% of the time. Six studies reported the mesiobuccal (MB) root of the maxillary second molar lies in closest proximity to FMS (3, 5-8), with a reported distances ranging from 0.18 mm to 2.76 mm. Additionally, all investigators reported buccal bone overlying MB roots of maxillary first premolar was thinnest ranging from 0.66 mm to 1.99 mm (6, 7, 10, 13).

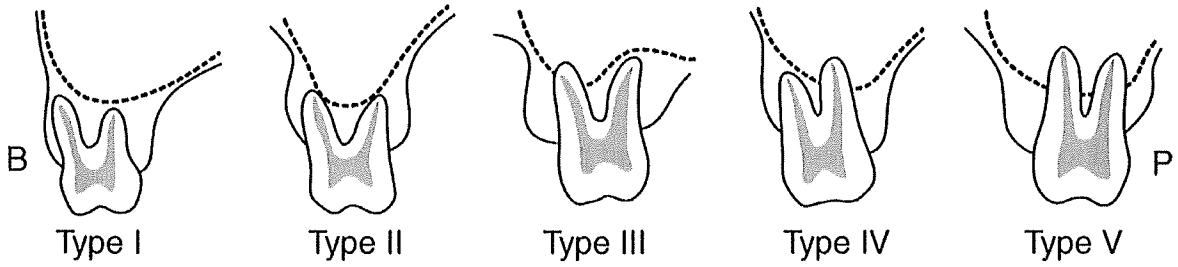
To date, two studies evaluated the effect of age on the vertical relationships between tooth apices and the FMS and concluded contradictory results. No studies have been published exploring relationships between buccal BT and posterior teeth. This retrospective review of CBCT scans analyzed linear relationships between maxillary posterior root apices and the FMS and the associated buccal BT in an adult population. A secondary objective attempted to correlate BT to subject ages.

Chapter II: Materials and Methods

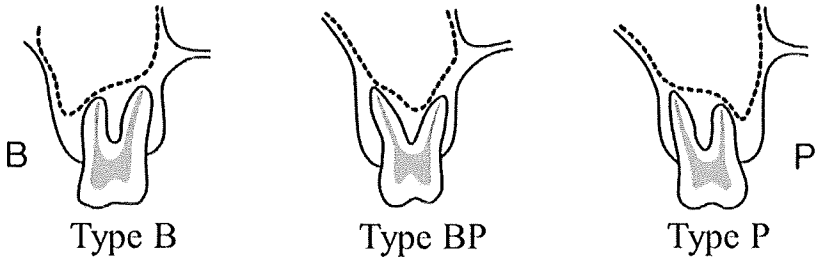
This study was approved by the Walter Reed National Military Medical Center Institutional Review Board. Archived CBCT scans, taken for diagnostic or clinical reasons unrelated to the study, were reviewed by a third party for the following inclusion criteria; adults (18 or older), limited field of view (FOV) CBCT, 5x5x5 cm^3 or less, of the maxillary posterior region, and a scan resolution up to 0.09mm. A scan was excluded if multiple maxillary posterior teeth (excluding third molars) were missing in the quadrant, a previous root end surgery had been performed, or there was evidence of significant osseous destruction or root resorption. All scans were captured between March 2013 and December 2016 using a CS9000 or CS9300 (CareStream© Dental, Rochester, NY). A subject's age and gender was recorded for scans meeting study criteria.

The anonymized CBCT scans were viewed on a Dell 20-inch monitor (1200 x 900 resolution) using a HP Compaq 8100 Elite Desktop (Harris County, TX). CareStream© 3D Imaging Software was used to reconstruct images at varying intervals between 0.076 mm to 0.09 mm up to an 5x5x5 cm^3 FOV. Each scan was evaluated in the coronal, axial and sagittal planes to descriptively define the vertical and modified horizontal classifications of the maxillary sinus to posterior tooth roots (Figure 1) as described by Kwak et al (6).

Figure 1: Vertical (top) and modified Horizontal (bottom) classification describing sinus position relative to roots as classified by Kwak et al (2004)



Type I = buccal and palatal roots are both inferior to the sinus
Type II = buccal and palatal roots are both superior to the sinus
Type III = buccal roots protrude into the sinus
Type IV = palatal roots protrude into the sinus
Type V = both buccal and palatal roots protrude into the sinus



Type B = sinus is located buccal to the buccal roots
Type BP = sinus is located between the roots
Type P = sinus is located palatal to the palatal roots

All linear distances were obtained using the CareStream© 3D Imaging Software measurement tool. The shortest vertical distance between the root apices to the closest border of the FMS was recorded in the corrected sagittal plane. This was accomplished by positioning the coronal plane along the long axis of the root in the sagittal view while bisecting the root in the axial view. Scans were measured using a maximized window in the oblique slicing view. Magnification, contrast and brightness were adjusted as needed to identify structures and key landmarks. If the root apex protruded into the sinus, a negative value was assigned to that root. The reference point of root entry was approximated based on the surrounding anatomy.

Buccal BT was measured at the optimal surgical resection level from the most buccal aspect of the corresponding root to the most buccal aspect of the cortical bone. For all teeth, with the exception of the MB root of the first molar, the resection level was 3.0 mm from the apex. For the MB roots of first molars this level was 3.6 mm from the apex. All molar palatal roots were measured from the most palatal aspect of the palatal root to the corresponding palatal cortical bone. All measurements were reviewed and verified by a board certified oral maxillofacial radiologist.

All statistical analyses were performed using R (R Core Team, 2016). Continuous data are summarized with 95% confidence intervals estimated via the t-distribution. Pearson's correlation was used to evaluate the correlation between age to bone thickness and age to distance; significance was evaluated at the .005 level to correct for the multiple comparisons made in each of these variables.

Chapter III: Results

Subject Demographics and Sample Distribution

The 128 CBCT scans meeting study criteria included 67 (52%) females and 61 (48%) males. Their ages ranged from 20 to 86 years old (yo) with a median age of 46. The subjects were categorized into 3 age groups; 48 (37%), 21-40 yo, 61 (48%), 41-60 yo, and 19 (15%) $\geq$ 60 yo. The 420 maxillary teeth consisted of 206 premolars and 214 molars. The distribution of the samples is seen in Table 1.

Table 1. Distribution of teeth

Teeth	Single root	Multiple roots
1st Premolar	47 (48%)	51 (52%)
2nd Premolar	91 (84%)	17 (16%)
1st Molar		108 (49%)
2nd Molar		106 (51%)

Sinus Relationship to Roots

The majority of the 214 molars, 85% (n=182), exhibited a combined type I and II vertical classification where all root apices appeared either inferior or superior to the sinus. The remaining 15% (n=32) presented as types III, IV and V where sinus appears pneumatized and envelops one or all of the roots. Only 54% (n=114) of molars had a definable horizontal relationship. In 95% (n=108) of these, the sinus was located in between the buccal and palatal roots (BP). The sinus was located between the buccal root and bone in only3.5% (n=4) of the molars and between the palatal root and palatal bone in 1.7% (n=2) of molars.

Table 2: Vertical and Modified Horizontal Classifications

Vertical Classification	Maxillary 1st molar	Maxillary 2nd molar
I	33 (30.6%)	36 (34.0%)
II	64 (59.3%)	49 (46.2%)
III	3 (2.8%)	11 (10.4%)
IV	5 (4.6%)	1 (0.9%)
V	3 (2.8%)	9 (8.5%)

Modified Horizontal Classification	Maxillary 1st molar	Maxillary 2nd molar
B	2 (3.1%)	2 (4.1%)
BP	62 (95.4%)	46 (93.9%)
P	1 (1.5%)	1 (2.0%)

Distance from Root Apices to the Floor of Maxillary Sinus

The buccal root of the first premolar was furthest from the sinus at 6.23 mm, 95% CI [5.53 mm, 6.92 mm] and the second molar MB root was closest at 0.53 mm, 95% CI [0.12 mm, 0.94 mm]. With respect to the buccal roots, as teeth transitioned posteriorly, the distance between the root apex to FMS decreased.

Table 3: Distance from root apex to the floor of the maxillary sinus

Tooth/Root	n		Mean Distance (mm)	Median Distance (mm)	CI lower (mm)	CI upper (mm)
	Single root	Multiple roots				
1st premolar/buccal	47		6.23	5.70	5.53	6.92
1st premolar/palatal		51	5.29	5.10	4.13	6.45
2nd premolar/buccal	91		2.78	1.80	2.24	3.32
2nd premolar/palatal		17	2.24	1.75	1.03	3.46
1st molar/mesiobuccal		108	2.29	1.30	1.77	2.81
1st molar/distal buccal		108	2.18	1.20	1.66	2.70
1st molar/palatal		108	1.54	1.10	1.03	2.05
2nd molar/mesiobuccal		106	0.53	0.60	0.12	0.94
2nd molar/distal buccal		106	0.87	0.60	0.42	1.32
2nd molar/palatal		106	1.40	1.00	0.91	1.88

Bone Thickness at Ostectomy Site

The mean buccal BT of the first premolar buccal root was 0.59 mm, 95% CI [0.48 mm, 0.70 mm] at the proposed ostectomy site and the thinnest for all teeth types. The thickest buccal BT was found over MB root of the second molar with a mean measurement of 2.31 mm, 95% CI [2.08 mm, 2.55 mm].

Table 4: Distance from root to the respective buccal or palatal surface

Tooth/Root	n		Mean Distance (mm)	Median Distance (mm)	CI lower (mm)	CI upper (mm)
	Single root	Multiple roots				
1st premolar/buccal	47		0.59	0.50	0.48	0.70
1st premolar/palatal		51	4.18	4.60	3.68	4.67
2nd premolar/buccal	91		1.07	0.80	0.89	1.24
2nd premolar/palatal		17	5.17	5.10	4.61	5.73
1st molar/mesiobuccal		108	0.63	0.40	0.46	0.80
1st molar/distal buccal		108	1.11	0.70	0.87	1.35
1st molar/palatal*		108	1.26	1.00	1.11	1.40
2nd molar/mesiobuccal		106	2.31	2.40	2.08	2.55
2nd molar/distal buccal		106	1.74	1.50	1.51	1.97
2nd molar/palatal*		106	1.35	1.00	1.14	1.55

* Indicates measurement from the palatal root to palatal cortical bone

Correlation to Age

Table 5 summarizes the Pearson correlation between each measured variable to patient age. Of the ten correlations performed for distance and bone thickness, only one (between distal from FMS to distal buccal second molar root and age) is significant at the .05 level, but none reaches a multiplicity adjusted alpha level of .005. Examination of this one correlation suggests as possibly spurious relationship. However, it is potentially interesting that all distances show a weakly increasing, though non-significant trend with increasing age.

Table 5: Pearson correlation between measured variables to age

Distance from FMS / Root	Correlation [R]	CI lower	CI upper	p value	n
1st premolar / buccal	0.08	-0.12	0.27	0.43	98
1st premolar / palatal	0.12	-0.15	0.37	0.39	54
2nd premolar / buccal	0.09	-0.1	0.27	0.37	111
2nd premolar / palatal	0.15	-0.37	0.6	0.58	16
1st molar / mesiobuccal	0.14	-0.05	0.33	0.14	106
1st molar / distal buccal	0.15	-0.04	0.33	0.13	106
1st molar / palatal	0.14	-0.05	0.32	0.16	107
2nd molar / mesiobuccal	0.18	-0.02	0.35	0.07	106
2nd molar / distal buccal	0.2	0	0.38	0.04	101
2nd molar / palatal	-0.05	-0.24	0.14	0.6	103

Bone Thickness / Root	Correlation [R]	CI lower	CI upper	p value	n
1st premolar / buccal	-0.11	-0.3	0.09	0.27	98
1st premolar / palatal	0.05	-0.23	0.32	0.71	51
2nd premolar / buccal	0.08	-0.11	0.27	0.41	108
2nd premolar / palatal	-0.39	-0.73	0.11	0.12	17
1st molar / mesiobuccal	0.07	-0.12	0.26	0.46	106
1st molar / distal buccal	0.01	-0.18	0.2	0.95	106
1st molar / palatal	0.03	-0.17	0.22	0.78	105
2nd molar / mesiobuccal	-0.07	-0.25	0.13	0.5	106
2nd molar / distal buccal	0.02	-0.18	0.21	0.85	101
2nd molar / palatal	0.14	-0.05	0.33	0.15	101

Chapter IV: Discussion

Kwak et al (6) found 72.8% & 81.0% of maxillary first and second molar had combined type I and II vertical relationships of the FMS to the root apices. Sharan and Madjar (3) and Yoshimine et al (9) reported maxillary first and second molars had a combined type I and II vertical relationships of 73.8% & 63.5% and 83.3% & 63.3% respectively. The 3 studies collectively reported a combined type I and II vertical relationships ranging from 72.8% to 83.3% for first molars and 63.6% to 81.0% for second molars. The combined type I and II relationship of maxillary first and second molars found in this study were 89.9% and 80.2% respectively.

In situations when the FMS is inferior to the apices of molar roots, horizontal relationships ranged from 80% to 97% and 72% to 80% type BP (sinus located between the roots) relationships respectively for first and second molars (6,8). This study found higher percentages of type BP, 95% in first molars and 94% in second molars. For first molars, the majority of studies report less than 7% of type B relationships. Second molars, however, had a higher incidence of type B relationships as described by Jung et al (8) at 27% and Kang et al (13) at 18.6%.

There is agreement between among all investigators that suggests molar roots do not extend into the maxillary sinus but instead are more likely to lie adjacent or in close proximity to it. The subjectivity of making these assessments and the various populations used in the studies could account for the minor variations reported. Panoramic imaging has been shown to overestimate root projection into the sinus by 39% (3). 3D imaging is more accurate and reliable in assessing these anatomic relationships in the maxillary posterior region.

Numerous studies have evaluated mean distances from root apices to the sinus. Eberhardt et al (7) used CT scans and found the MB root of the second molar closest to the sinus at 0.83 ± 0.49 mm and the palatal root of the first premolar furthest at 7.05 ± 1.92 mm. Other studies have confirmed these findings using panoramic radiography (3, 5), cadavers (6, 14) and more recently CBCT scans (9-13, 15). Previous CBCT studies used different planes to measure the distance of root apices to sinus. Kilic et al (15) used coronal planes and Georgescu et al (5) used sagittal planes to evaluate posterior teeth. Von Arx et al (11) measured the distance of sinus to root apices in premolars in all three planes and found the coronal plane tends to overestimate the distance and did not truly represent the shortest distance. This study used a corrected sagittal plane to measure the distance from root apex to FMS.

The majority of studies report the MB root of the maxillary second molar lies in closest proximity to FMS ranging from 0.18 to 2.82 mm (5-10, 12, 13). The first premolar is consistently reported as furthest from sinus with a range from 5.15 to 7.56 mm (5-7, 9, 10, 12, 13, 15). This study also found the root apices closest to FMS were MB roots of second molars with a mean distance of 0.53 mm, 95% CI [0.12 mm, 0.94 mm] and those furthest away the palatal root of first premolars with a mean distance of 6.23 mm, 95% CI [5.53 mm, 6.92 mm]. These findings are in agreement with numerous investigators. While the data from research provides a guide for clinicians performing apical surgery, a CBCT may be warranted to elucidate the patient's true anatomy.

Buccal BT is an important morphologic factor when treatment planning for apical surgery. Previous studies have evaluated buccal BT from various reference points contributing to the wide variation in the measurement. Early studies (6, 7) measured BT from the tooth apex to the buccal bone while others evaluated the BT from midroot (8, 9) and most recently,

Lavasani (10) evaluated BT from the proposed surgical site. Of studies evaluating both molars and premolars, published data confirms the first premolar has the thinnest buccal BT from 0.66 to 1.99 mm (6, 7, 10 ,13) and the BT of MB root of the second molar is the thickest from 1.91 to 5.48 mm (6, 7,10, 13). Studies evaluating the BT from the anatomical root apex generally were thicker while those measured at the proposed surgical site were thinner. Eberhardt et al (7) used CT scans with a large FOV. The low resolution images would make it difficult to capture precise measurements. Kwak et al (6) utilized cadaver tissue which allowed for only a single cross sectional measurement for each tooth. Only Lavasani's group (10) evaluated buccal BT at the site of proposed surgical resection (3.0 and 3.6 mm) and used CBCT with varying FOV. They reported mean BT in the premolar buccal region from 0.66 to 1.35 mm and 0.84 to 1.91 mm in the molar region. These findings are similar to the results of this study at 0.59 mm, 95% CI [0.48 mm, 0.70 mm] to 1.07mm, 95% CI [0.89 mm, 1.24 mm] and 0.63 mm, 95% CI [0.46 mm, 0.80 mm] to 2.31 mm, 95% CI [2.08 mm, 2.55 mm] in the premolar and molar regions, respectively. The present study utilized only limited FOV CBCTs for measurements.

With the exception of the second molar buccal roots, this study found that removing 2 mm of bone at the ostectomy site would expose greater than 84% of buccal roots. Removing 2 mm of buccal bone in the second molar region will expose only 39.6% of MB roots and 59.4% distal buccal roots.

A previous study by von Arx et al. (11) evaluated only premolars and concluded age, side or the absence of one premolar are not related to the mean distance between tooth apices and the FMS. However, Tian et al. (12) reported younger age groups correlated with shorter mean distance from apices to the FMS when compared to older individuals in a Chinese population.

This study evaluated three different age groups and concluded no correlation between age and BT.

Chapter V: Conclusion

Data from this research indicate the first premolar buccal root measured the longest distance to the FMS at 6.23 mm, 95% CI [5.53 mm, 6.92 mm] and the thinnest buccal bone at the site of root resection at 0.59 mm, 95% CI[0.48 mm, 0.70 mm]. The reverse is true for the second molar MB root that measured the shortest distance to the FMS at 0. , 95% CI [0.12 mm, 0.94 mm] and the thickest buccal bone of 2.31 mm, 95% CI [2.08 mm, 2.55 mm]. With the exception of the second molars, removing approximately 2 mm of buccal bone will expose 84% of the buccal roots. There was no identifiable correlation between age and buccal BT.

The use of CBCT, if available, is recommended when treatment planning for endodontic apical surgery, however, in the absence of a 3D technology, being informed of the available information of the surgery site can help improve clinical success.

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